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A Method for Measuring the Effectiveness of Gaseous Contaminant Removal Devices Progress Report

Bal M. Mahajan

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Building Technology
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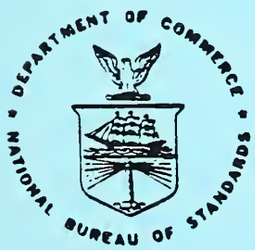
September 1987



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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Acting Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

A research effort to develop test methods for measuring the effectiveness of gaseous contaminant removal devices is underway. The objectives of the initial phase of the research effort were to devise or select a practical test method, design a test apparatus suitable for this purpose, develop techniques that would permit automation of all aspects of the testing scheme, and conduct preliminary experiments to demonstrate the feasiblity of the testing scheme. Various aspects of the testing scheme include : supply of conditioned air at constant flow rate with a constant value of relative humidity for duration of the tests; safe means of contaminating the conditioned air with known gaseous contaminants at desired concentrations; and means for measuring the contaminant concentration both upstream and downstream of the filter media.

This progress report briefly describes the test apparatus designed for measuring the effectiveness of filter media, various components of the test loop, instrumentation, and contaminant concentration measuring techniques. The report also describes various aspects of the planned testing scheme that will be followed to accomplish the goals of this research project.

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1. INTRODUCTION

Filtering devices using granular materials called filter media (or sorbers), such as activated carbons and chemically treated alumina and other organic substances, are being used to remove or chemically change gaseous pollutants which are found in buildings. These devices can be incorporated into the heating, ventilation and air conditioning (HVAC) systems of building, in a manner similar to filters used for the removal of particulate. Particulate filters can be evaluated by using the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 52-76 [1]. Over the years, attempts have been made to evaluate gaseous removal filters for some specific applications; however, no general procedures are available for evaluating the effectiveness of these devices. Methods are needed to provide acceptable means to evaluate these devices so that an effective and economical control method can be promoted for improved indoor air quality.

A research effort to develop the needed methods was initiated at the National Bureau of Standards (NBS). The objectives of the initial phase of the research effort were to devise or select a practical test method, design a test apparatus suitable for this purpose, develop techniques that would permit automation of all aspects of the testing scheme, and conduct preliminary experiments to demonstrate the feasiblity of the testing scheme. Various aspects of the testing scheme include : supply of conditioned air at constant flow rate with a constant value of relative humidity (Rh) for long periods of times (from several hours to several months); safe means of contaminating the conditioned air with known gaseous contaminants at desired concentrations; and means for measuring the contaminant concentration, both upstream and downstream of the filter media. The testing apparatus should be designed to permit simulation of operating conditions, particularly the filter medium face and/or bed velocities, without exuberant cost of running the tests.

This progress report briefly describes the selected test method and test apparatus designed for measuring the effectiveness of filter media, various components of the test loop, instrumentation, and contaminant concentration measuring techniques. The report also describes various aspects of the planned testing scheme that will be followed to accomplish the goals of this research project.

2. CONSIDERATION FOR A PRACTICAL TEST METHOD

Effective design of gaseous contaminant removal equipment for HVAC systems is a challenging undertaking. Designers need to know gaseous contaminants that are to be removed from the conditioned space, the probable contaminants concentration or source of internal generation, and allowable or safe concentration of these contaminants. Designers also need the following information on gaseous contaminant removal devices: removal efficiency or contaminant penetration at operating levels; useful life of the device and maintenance requirements; sensitivity to humidity and temperature; and the nature of any effluent products created by the device. The selected test

method must, therefore, facilitate the acquisition of performance as well asuseful life expectancy data for gaseous contaminant removal devices.

Adsorption of vapors or gaseous adsorbates by granular adsorbents has been studied by many researchers for gas-mask canisters and respirator cartridges [2-10]. There also exist some performance test methods and standards for filter media used in respiratory protective devices and other specialized applications [11-16]. Various methods that have been used for studying the performance of gaseous contaminant sorbers are summarized by Rivers [17]. These methods include : (1) complete Isotherm; (2) one-point isotherm; (3) breakthrough or time to set penetration; (4) integrated penetration or penetration at set inlet concentration (load); (5) odor breakthrough or perceived breakthrough; and (6) penetration versus load or penetration as a function of elapsed time and inlet concentration.

The first method, the complete isotherm, could be used to estimate the field performance of such devices for a set of assumed contaminants and operating conditions. The translation of the isotherm into filter penetration and life is, however, a laborious undertaking, and far beyond the interest and scope of HVAC system designers and this research effort. Methods 2 through 5 provide only order-of-magnitude performance data, and are essentially quality-control procedures [17]. Method 6, namely penetration versus load, appears to be best suited for our purpose.

In the penetration versus load method, a filter medium is challenged with a known gaseous contaminant introduced into the intake air at a known concentration (C_i or load) and the concentration downstream of the filter medium (C_o or exit concentration) is measured for various elapsed times. A dimensionless quantity called penetration (C_o/C_i) is computed from the measured value of quantities C_i and C_o. It is important to point out that penetration is equal to one minus efficiency. This method can provide needed data, namely contaminant removal efficiency and useful life of sorbers, for at least one contaminant at the operating conditions of the test. This method, we believe, can also be used to measure the performance of filter media for contaminant mixtures.

Gaseous contaminant removal performance of a filter medium is dependent on many factors, which include the following:

1. Filter parameters:
   a. Type of sorber (that is, whether the filter material is a physical adsorber, an absorber, a chemisorber, or a catalyst).
   b. Surface properties of sorber material.
   c. Granule size.
   d. Packing density.
   e. Filter bed depth.

2. Gaseous contaminant parameters:
   a. Number of contaminants (that is, one gas or a mixture of gases).
   b. Physical and chemical properties of the contaminant.
   c. Contaminant concentration (or load).

3. Carrier air parameters:
   a. Temperature.
   b. Relative humidity.
   c. Flow rate and/or bed velocity.
   d. Presence of trace amounts of other gaseous contaminants.

4. Other factors:
   a. Previous history of the filter medium, particularly its adsorbed load of contaminants and water vapor.
   b. Generation of contaminants by the sorption device.

Evaluating every filter medium for ranges of all the listed factors is impractical. Therefore, it is important to narrow down the number and ranges of parameters as much as possible. Initially, we will examine the influence of some of the filter media parameters, gaseous contaminant parameters, and carrier air parameters. The effects of the remaining factors on gaseous contaminant removal performance of filter media will be examined during the subsequent phases of the project.

The test method will employ an open test loop system in which sample filter media will be challenged with known gaseous contaminants introduced into the intake air. Compressed laboratory air will be conditioned to desired levels of humidity and temperature; the conditioned air will be contaminated with a known gaseous contaminant at desired concentrations; and the contaminated air will pass through the filter where the contaminant will be removed. The contaminant concentration upstream of the filter media (C_i) and downstream of the filter media (C_o) will be measured using gas chromatography. Data on filter media penetration (i.e., C_o/C_i) as a function of elapsed time and other relevant factors will be collected. These data will be utilized to determine breakthrough conditions and life and or capacity of the filter media. These data will also make it possible to compare the performance of different filter media and to estimate system effectiveness and cost.

3. TEST APPARATUS

The apparatus for measuring the performance of filter media will utilize the test canister described in the ASTM Standard D3803 [13] with some design modifications. The ASTM test canister is of practical size for small-scale tests of granular adsorbers, chemisorbers and catalysts. The canister is small enough to allow convenient control of all the desired test conditions, and yet large enough to average out the filter media variations and avoid significant edge effects [17]. The canister is intended for a face velocity of 0.2 m/s (40 fpm); however, tests can be conducted at face velocities as high as 0.4 m/s (80 fpm). Scrubbers, and other gaseous contaminant removal devices may require a larger test apparatus, but the cost of running the tests encourages use of the smallest representative of the prototypes.

The schematic of the basic test apparatus is shown in Figure 1. It is an open loop system consisting of four principal components: an air supply section, a test section, a contaminant generation section, and an analysis

section. A brief description of the four components is given below.

3.1 AIR SUPPLY SECTION

In this section humidity, temperature, and flow rate of air for experiments are adjusted to desired values and monitored. Compressed laboratory air at room temperature is conveyed through a 6.4 mm inside diameter (ID) nylon tube via a manually operated pressure regulator (PR1) followed by a computer controlled flow regulator (FR1). The flow regulator FR1 will regulate and monitor the flow rate of air flowing to the system. From this point the air can be sent directly to the humidification section or, if desired, it can be routed to the humidification section through a pre-filter section. The pre-filter, depending on the need, may consist of: silica gel as a drying and general absorbing medium; activated carbon as a general control medium; and any other filter medium needed to remove specific trace contaminants.

The humidification section is shown schematically in Figure 2. It consists of a controller, a chilled water circulator bath, a constant temperature water vessel, and a water reservoir. The circulating bath can also be heated if desired. Only distilled water is used in this system. Water from the chilled water circulator bath circulates through the constant temperature water vessel containing a platinum resistance temperature detector (RTD) for monitoring the temperature of the water. The flow rate of the circulating water and the temperature of water in the vessel are adjustable. The constant temperature water vessel consists of a heavily insulated polyethylene bottle; the bottle is placed in a rectangular container fabricated with polyvinyl chloride (PVC) panels and the space between the bottle and container is packed with insulating material. The water reservoir is connected to the water circulator bath to replenish the water used in humidifying the air.

Air at room temperature (22-24°C) enters the constant temperature water vessel via a finely perforated nylon tube, bubbles through the water chilled to any desired temperature, passes through a restrainer, and leaves the vessel nearly saturated at the vessel temperature from the top in a 10.5 mm ID 3 m long nylon tube. The air is then routed through a 10.5 mm ID 1.5 m long stainless steel tube to a measurement section. During its passage through these tubes air is heated back to room temperature.

The measurement section is a combination of 10.5 mm ID nylon and stainless steel tubes, where the temperature and relative humidity of the air are monitored with a thermistor and a dew point hygrometer respectively. At this point air may either be routed to the test section or it may be sent to the exhaust hood. By maintaining constant temperature and water level in the constant temperature vessel the relative humidity of the supply air can be maintained at nearly a constant value for any length of time. The value of relative humidity can be changed by changing the temperature of water in the vessel. When the flow rate and relative humidity of the supply air has been properly adjusted to the desired value, the conditioned air is then directed to the test section and the testing is initiated.

3.2 Test Section

The test section, including important dimensions of its various parts, is shown schematically in Figure 3. All parts of the test section have been fabricated with stainless steel materials. The test section consists of three sub-sections: air contamination section; test canister assembly, and exhaust. These three sub-sections and their components are listed below, and the listing follows the direction of the air flow.

The Air Contamination Section consists of the following: A 10.5 mm ID tube, containing a port 'P0' for adding gaseous contaminant to the air stream; a 6.4 mm ID tube, which is connected to a 10.5 mm ID tube, about 260 mm long, ending in a 90° elbow; a 10.5 mm ID tube, leading to the top end cap of the test canister assembly, and containing a port 'P1' for withdrawing samples of contaminated air for measuring the inlet contaminant concentration (C_i) or contaminant load. The contaminated air enters the test canister assembly through the side wall, where the air flow expands as well as changes its direction by 90 degrees.

The Test Canister Assembly consists of the following cylindrical vessels: a top end cap; two interchangeable test canisters (one 25 mm deep and one 51 mm deep), only one of the two test canisters has the filter media, and the canister containing the filter media is followed by the empty canister; and a bottom end cap. The side wall of the bottom end cap is fitted with a 10.5 mm ID tube, containing a port 'P2' for withdrawing samples of the filtered air for measuring the contaminant concentration downstream of the filter (Co).

The details of the test canister are shown schematically in Figure 4. It essentially is the test canister described in ASTM D3803 with some design modifications suggested by Rivers [18]. The canister is a 52 mm ID, 25.4 mm or 50.8 mm long, cylindrical vessel. Both ends of the canister are specially designed to accommodate a perforated screen, a baffle ring, and a snap ring at each end. One of the ends also accommodate an O-ring. The space between the two perforated screens is packed with the filter medium.

The Exhaust system, primarily, consists of the laboratory exhaust hood. The open end of the tube of the bottom end cap containing port P2 is connected to a rotameter type flowmeter (FR1) for monitoring the flow rate of air flowing through the test apparatus. Air leaving the rotameter is routed to the laboratory exhaust hood via a 10.5 mm ID nylon tube. The location of the rotameter has been indicated in Figure 1. The tube leading to the exhaust hood is not shown in any Figure.

Conditioned air will enter the 10.5 mm ID tube of the air contamination section. The gaseous contaminant will be introduced into the air stream through port P0 at a constant flow rate. The passage of the contaminated air through the reduced diameter tube and 90 degree elbow will enhance the mixing process. The contaminated air will then flow through the test canister assembly containing the filter medium where a portion of the gaseous contaminants will be removed. The air will then be exhausted into the exhaust hood. Samples of contaminated air will be drawn through ports

P1 and P2 at regular intervals and sent to a gas chromatograph where they will be analyzed for the purpose of measuring the contaminant concentrations C_i (load) and C_o (exit concentration).

3.3 Contaminant Generation Section

The contaminants, which are gases at room temperature, will be acquired as high purity commercially available compressed bottled gases. The high purity gaseous contaminant from a compressed cylinder will be routed to port P0 of the test section in a 3.2 mm outside diameter (OD) nylon tubing. A manually operated pressure regulator (PR2), a computer controlled flow regulator (FR2), and a rotameter type flowmeter (FM2) will be placed in the gas line for adjusting and monitoring flow rate of the contaminant. The location of these instruments has been indicated in Figure 1.

The contaminants, which are liquids at room temperature, will be used in the tests as follows. A nearly saturated mixture of air and contaminant vapor will be generated for the experiments. The apparatus for this purpose is shown schematically in Figure 5. It consist of three vessels (A1, A2 and A3) in series; vessels A1 and A2 contain liquid contaminant at room temperature and vessel A3 is empty. Compressed clean air at room temperature will be conveyed to vessel A1 through a 3.2 mm OD nylon tubing via a manually operated pressure regulator (PR2) followed by a computer controlled flow regulator (FR2) for adjusting the flow rate of air. The air from vessel A1 will be sent first to vessel A2 and then to vessel A3.

Passing through the liquid contaminant in vessels A1 and A2, the air will be nearly saturated with contaminant vapors; vessel A3 will serve to remove any contaminant droplets which might be entrained in vessel A2. This nearly saturated air and contaminant vapor mixture from vessel A3, will be sent to port P0 of the test section via the rotameter FR2.

3.4 Analysis Section

Analysis section consists of a computer controlled gas chromatograph (GC) with a packed stainless steel column, a ten port automatic gas sampling valve, and a flame ionization detector (FID). The gas chromatograph can be operated with two detecting systems. It can also be operated with most detectors including: electron capture detector (ECD), flame ionization detector (FID), flame photometric detector (FPD), hot wire detector (HWD), Nitrogen Phosphorus detector (NPD), and thermal conductivity detector (TCD).

Air samples, S1 from port P1 and S2 from port A2, will be conveyed to the GC for analysis via the ten port sampling valve. The flow path that will be used is shown schematically in Figure 6. The flow path uses one carrier inlet, one column, and one detector, and two loops; loop L1 for sample S1 from port P1, and loop L2 for sample S2 from port P2. The contaminant concentration data along with other relevant data will be recorded for further analysis. The exhaust gases from the GC will be sent to the laboratory exhaust hood.

4. CURRENT STATUS

The test apparatus has been designed, fabricated and assembled. Initial checking of various parts of the apparatus and instrumentation has either been completed or is underway. The gas chromatograph has been acquired, installed and inspected. Three different grades of carbons (filter medium) have been acquired, and two more carbons, from a different vender, are being acquired. The gaseous contaminant (n-Butane) to be used in the initial experiments has been acquired. Development of computer software for controlling the experiments and analyzing the test data is underway.

5. PLANNED ACTIVITIES

Most of the experiments will be conducted at room temperature (22-24°C) using moist air having three different values of relative humidity, about 30, 40, and 50 per cent. Initial tests will be conducted with 2-Butane as the gaseous contaminant and a coal based carbon as the filter medium. The surface area and bulk density of the selected carbon are 600 to 700 m^2/g and 0.55 to 0.60 g/cc respectively. During the initial tests, the test apparatus, various instrumentation, software, and the testing procedures will be checked and debugged, and modified if necessary.

The conditioned air (about 30% relative humidity, and 22-24°C) will be contaminated with 2-Butane to achieve a concentration level of about 100 parts per million (ppm); subsequent tests will be conducted with 2-Butane concentrations of about 150 ppm, 75 ppm and 30 ppm. During these experiments data on the contaminant concentration upstream of the filter medium (C_i) and downstream of the filter medium (C_o) will be collected as a function of elapsed time. These data will be plotted as penetration (C_o/C_i) versus dimensionless elapsed time (t/τ) as shown in Figure 7. Where τ is the residence time (the time spent by a vapor or gaseous contaminant in a bed of filter media granules).

Subsequently, experiments with other gaseous contaminants and filter media will be conducted by following the procedure outlined above. Gaseous contaminants for the experiments will be selected according to their possible adverse health effects, and their presence in the indoor air. Selected contaminants will include representatives of various classes of volatile organic compounds (VOC). For example: methanol for alcohols; formaldehyde or hexanal for aldehydes; trimethylpentane for alkane; toluene for aromatic hydrocarbons; trichloroethane for halo-carbons; 2-butanone for ketones; etc.

During this work, close cooperation with the ASHRAE technical committee on gaseous air contaminants and gas contaminant removal equipment (TC 2.3) will be maintained. The findings of the initial experiments will be shared with members of this committee; and their suggestions regarding the selection of filter media and gaseous contaminants will be sought. In this way, it is expected that the ASHRAE would use the results of this study as a basis for promulgating a consensus standard.

6. ACKNOWLEDGMENT

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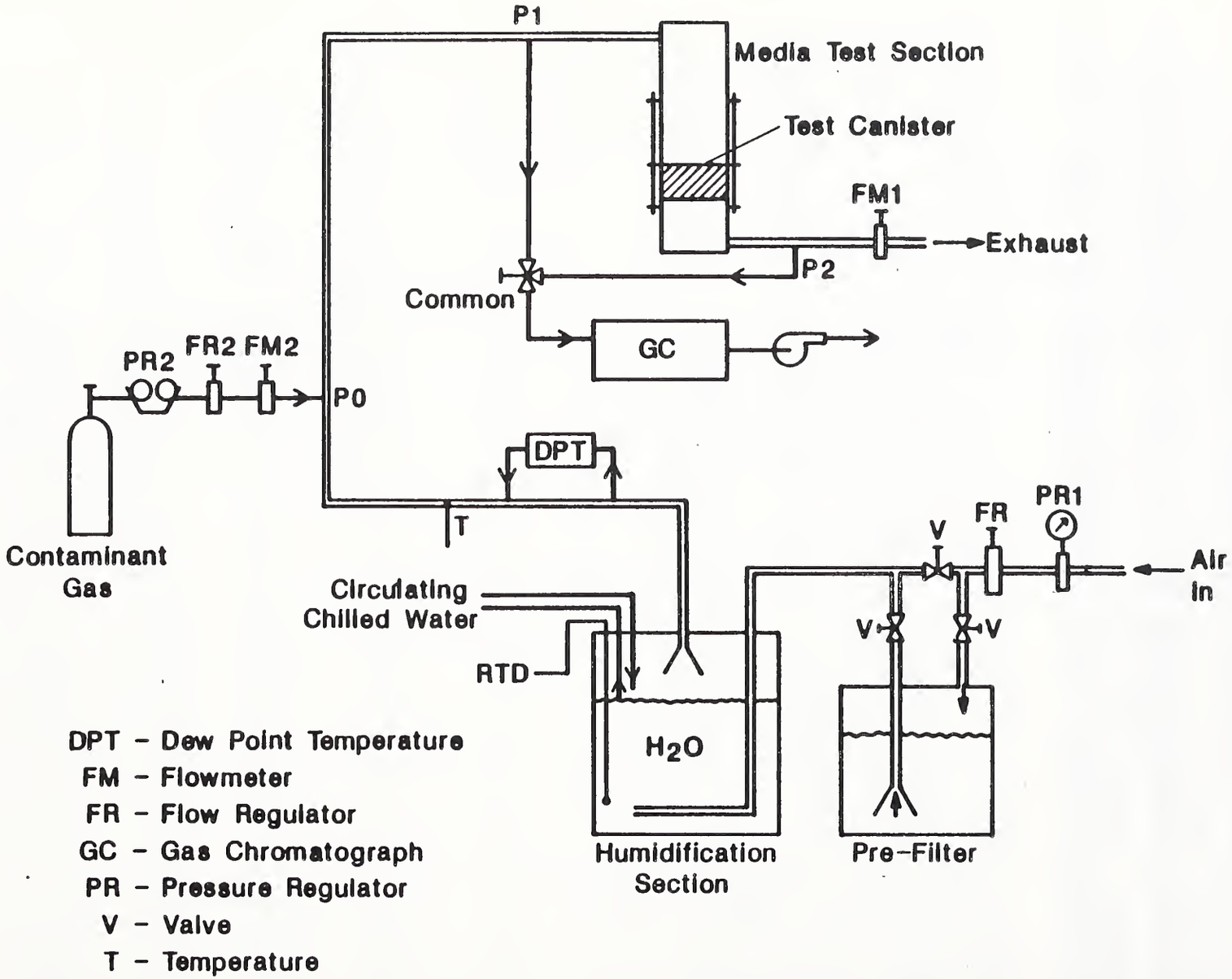


Figure 1. Schematic of test apparatus

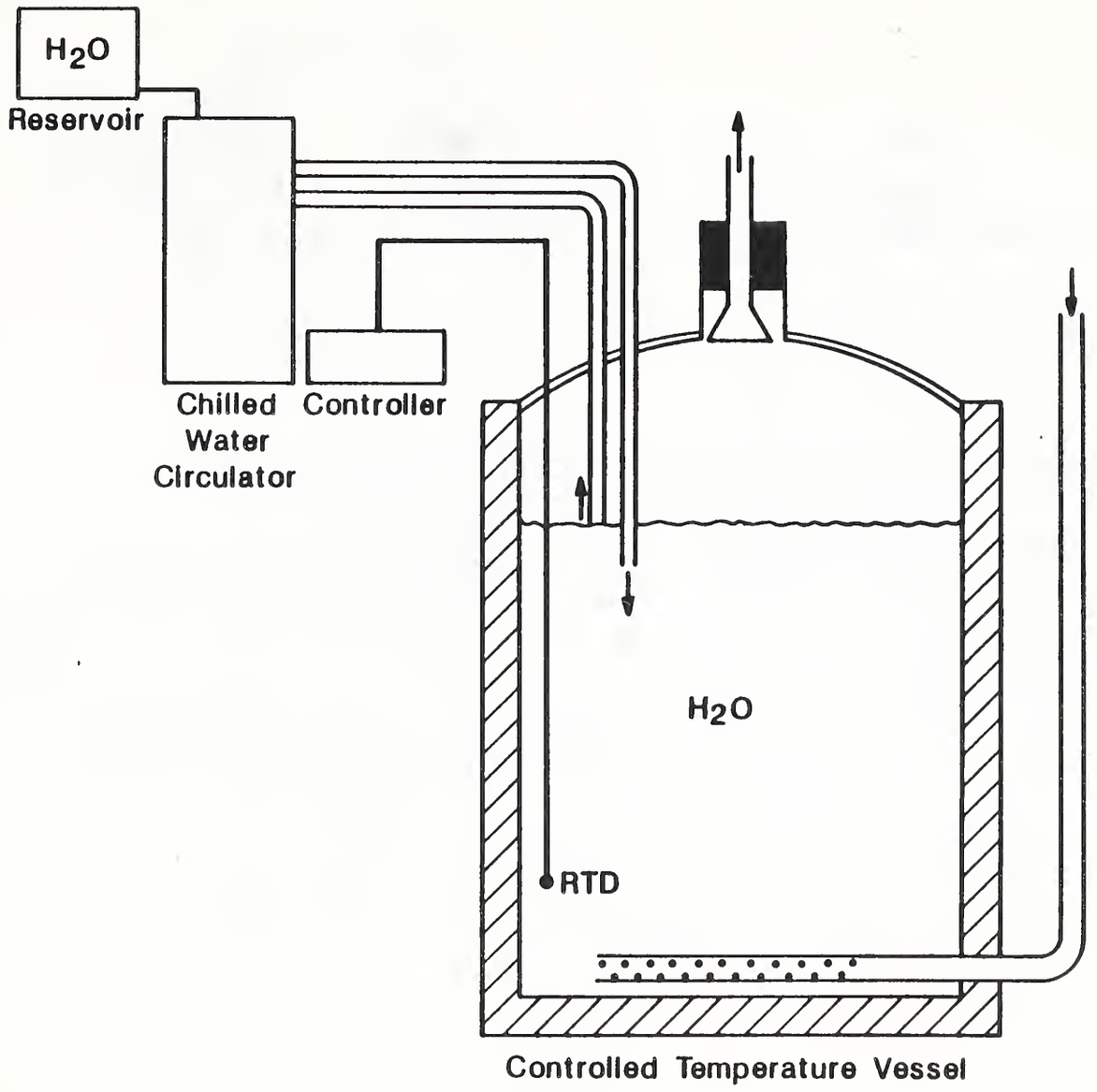


Figure 2. Schematic of humidification section

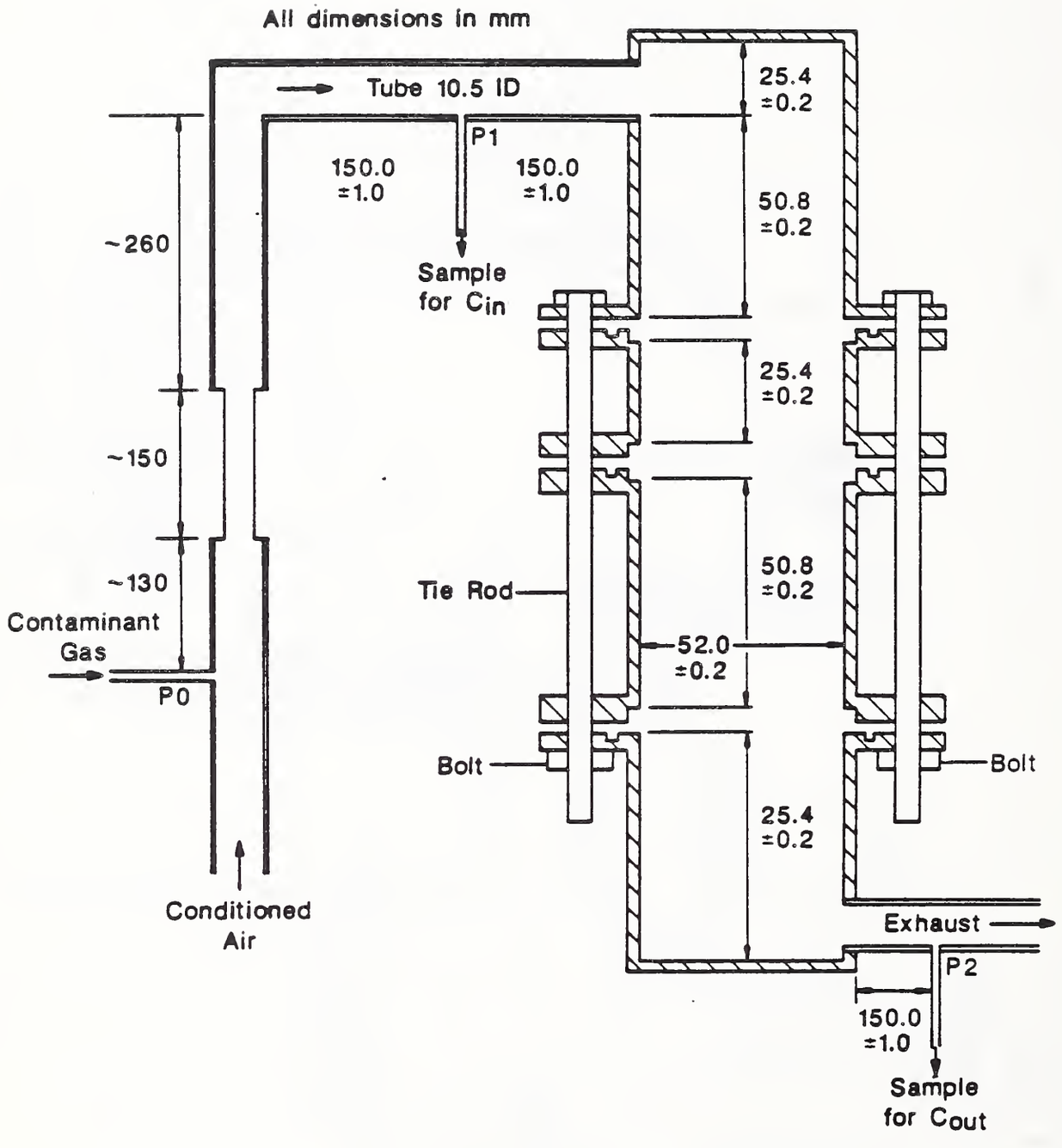
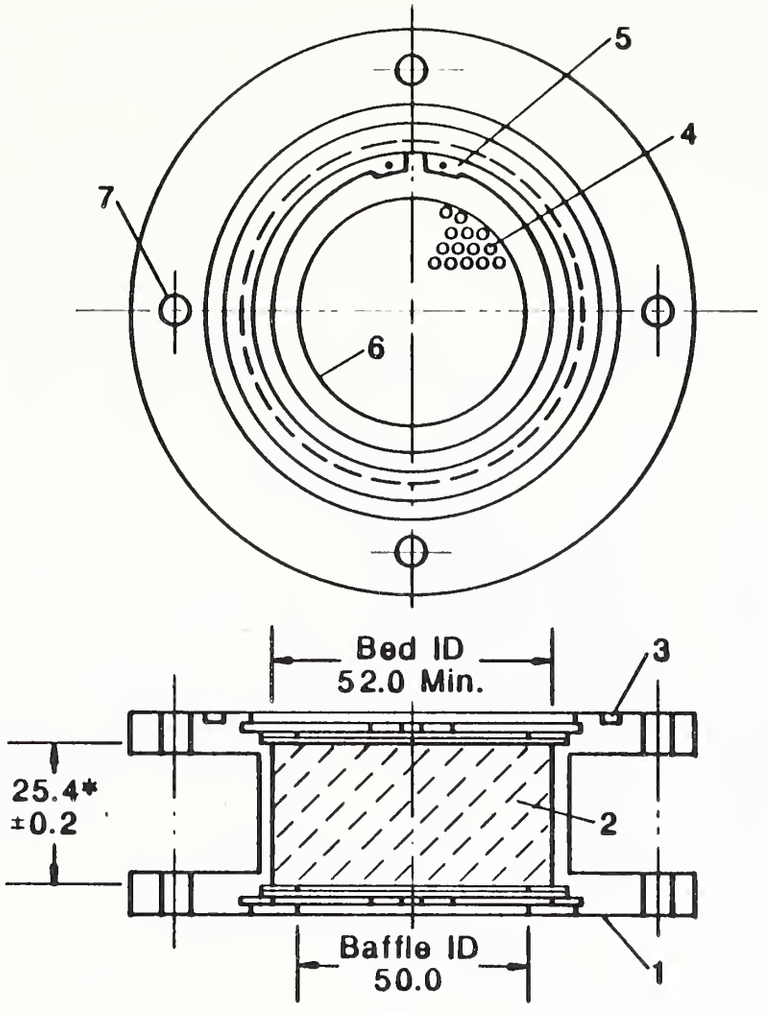


Figure 3. Schematic of test section



1 - Bed holder
2 - Sorption media
3 - O-ring gland
4 - Perforated screen (each end)
5 - Snap ring (each end)
6 - Baffle ring (each end)
7 - Holes for assembly tie rods (4)

Holders can be stacked to simulate deeper beds

*For some canisters depth is 50.8

All dimensions in millimeters

Figure 4. Schematic of media test canister

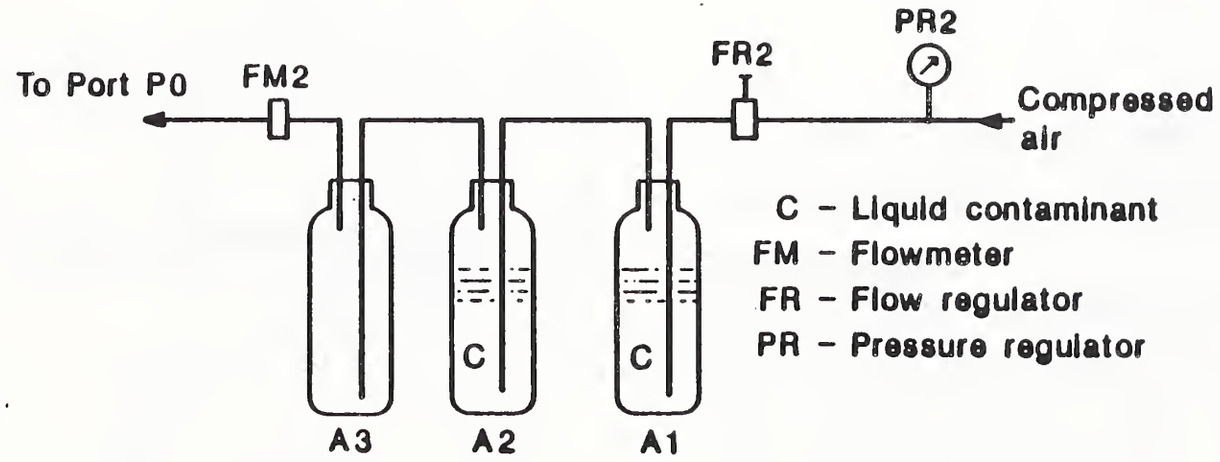
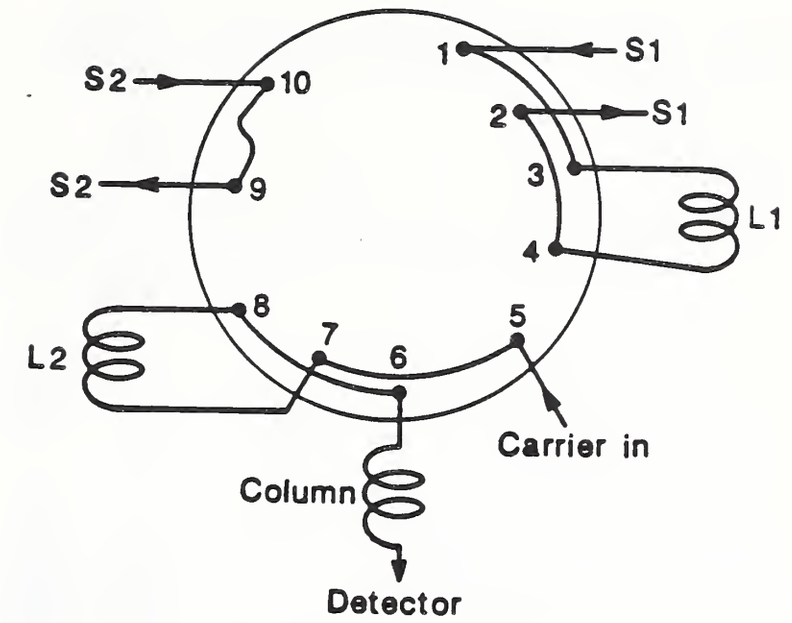


Figure 5. Schematic of contaminant generation apparatus



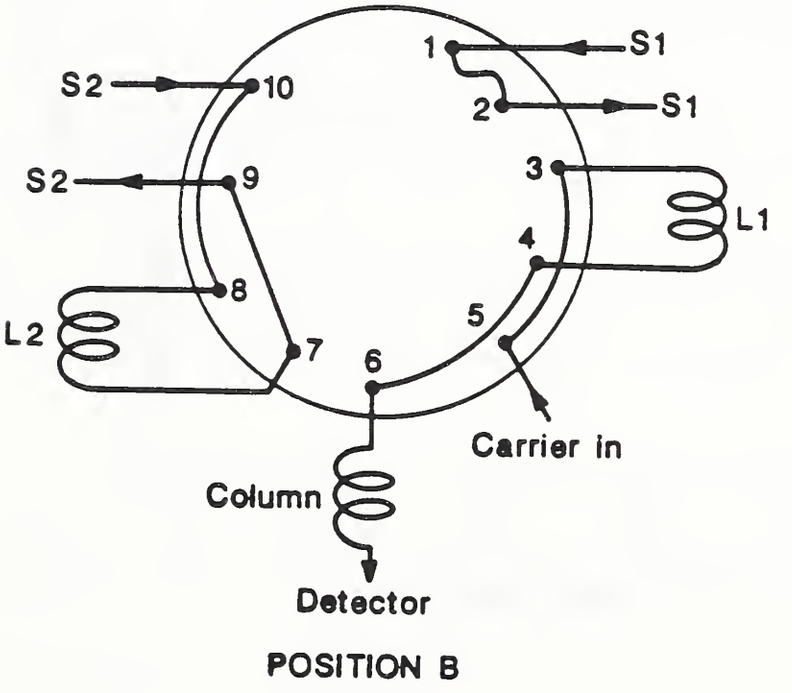


Figure 6. Schematic flow path for the ten port valve

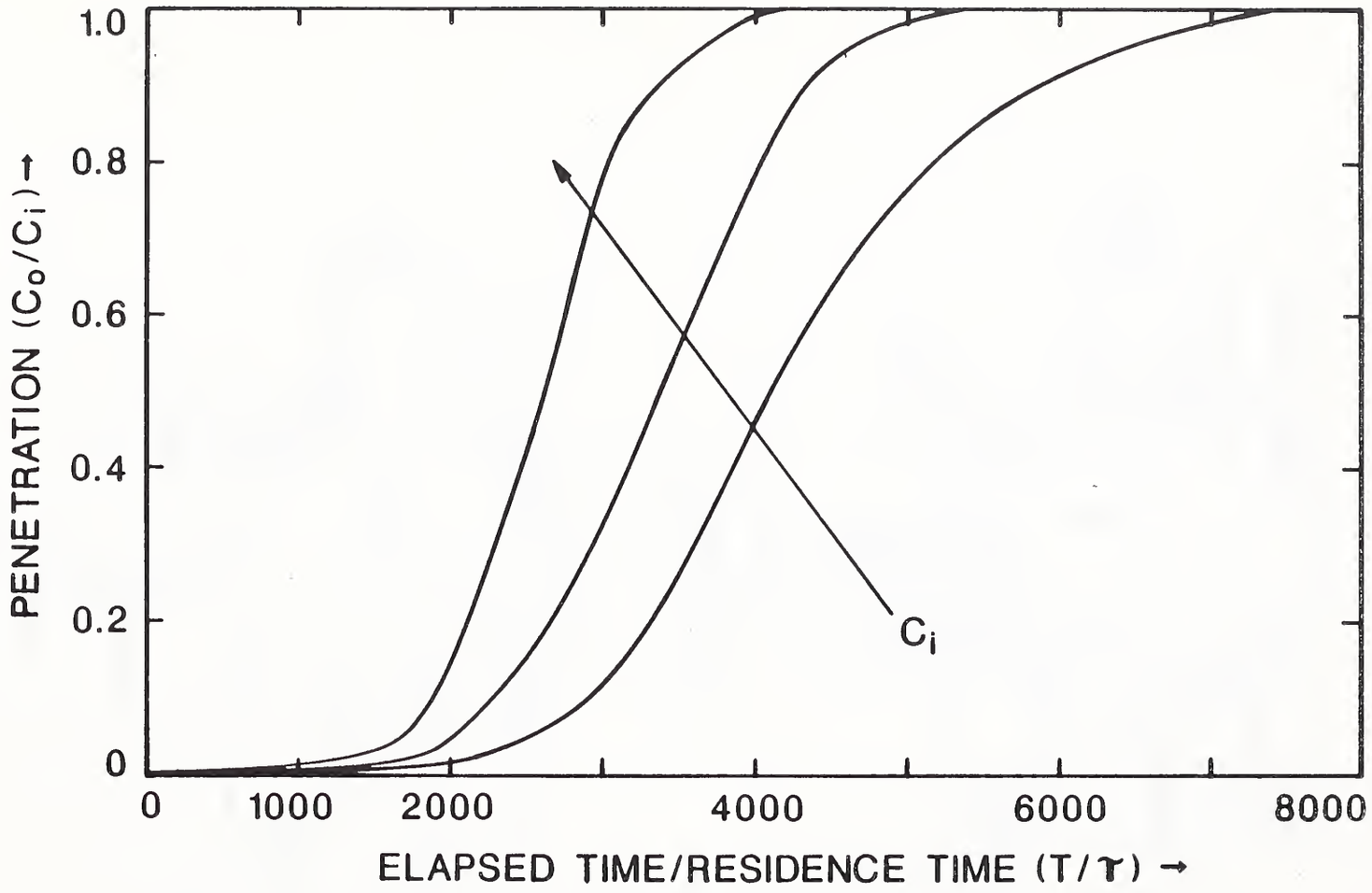


Figure 7. Penetration as a function of dimensionless elapsed time

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A research effort to develop test methods for measuring the effectiveness of gaseous contaminant removal devices is underway. The objectives of the initial phase of the research effort were to devise or select a practical test method, design a test apparatus suitable for this purpose, develop techniques that would permit automation of all aspects of the testing scheme, and conduct preliminary experiments to demonstrate the viability of the testing scheme. Various aspects of the testing scheme include: supply of conditioned air at constant flow rate with a constant value of relative humidity for the duration of the tests; safe means of contaminating the conditioned air with known gaseous contaminants at desired concentrations; and means for measuring the contaminant concentration both upstream and downstream of the filter media.

This progress report briefly describes the test apparatus designed for measuring the effectiveness of filter medias, various components of the test loop, instrumentation, and contaminant concentration measuring techniques. The report also describes various aspects of the planned testing scheme that will be followed to accomplish the goals of this research project.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

apparatus; contaminants; device; effectiveness; filter; gaseous; media; method; removal; sorber; test

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